How to extend flight time and battery life of quadcopters and industrial drones

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Farnell Webinar
Agenda

• High-Speed Sensorless-FOC for drone ESC
• Battery Pack for drone
High-Speed Sensorless-FOC for drone ESC
Agenda

- Overview of a Drone
- Trapezoidal vs Sinusoidal considerations
- Software considerations
- Test results and setup
- Design Overview
Non – Military Drones – **Subsystems**

**Flight Controller**
Brain of the flying system, Accepts the commands from remote, Interfaces with sensors systems and controls ESCs, Camera commands, Gimbal, Stability etc. Assist in image transmission

**Battery Pack**
1s/2s/4s/6s Li-ion or Li-Po batteries, Supplies the Power to each of the system components

**ESC – Electronic Speed Controller**
Typically 4 or more, Brushed DC or Brushless DC motor, Speed control for thrust and direction change

**Flight Controller**

**Flight**

**Payload (App dependent)**

**Gimbal Controller**
Controls and holds the camera angles in 1/2/3 axis

**Camera Module**
Captures the Images / Videos per received commands, sends the data to remote system or stores in SD card.

**Vision and Sensor systems**
Multiple Sensors (Ultrasonic/ LiDar / IR / Accelero / Gyro) for collision detection, Landing assist , stability, all interfaced to main controller . GPS for navigation

**Remote Controller**
Takes the inputs (flight control/capture) from user and sends the commands to Flight controller, optional Screen interface ( maybe phone / tablet as well)

**Battery Pack**
1s/2s/3sLi-ion or Li-Po batteries, Supplies the Power to remote controller
System Description & Problem Statement

ESC – Electronic Speed Controller
Typically 4 or more, Brushed DC or Brushless DC motor, Speed control for thrust and direction change

This limits the efficiency of the motor and the speed performance due to torque ripple caused by the Control, the control also limits the dynamic performance of the speed change which causes the drone to react slower then by FOC control

Changing the Trapezoidal Control to FOC (Field Oriented Control) would remove the torque ripple which would create a more smooth motor movement, hence improving efficiency

One issue with FOC control is the need for an accurate angle, hence the sensor is expensive
Therefore FOC control is only interesting if it can be done sensorless
High-Speed Sensorless-FOC for drone ESC
Block Diagram Trapezoidal vs Sinusoidal
<table>
<thead>
<tr>
<th></th>
<th>Trapezoidal(BLDC)</th>
<th>Sinusoidal(FOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commutation of Motor</td>
<td>Block commutated control</td>
<td>Field Oriented Control</td>
</tr>
<tr>
<td></td>
<td>60 Degree angle measurement</td>
<td>Real time accurate angle measurement</td>
</tr>
<tr>
<td>Sensorless Control</td>
<td>Zero Crossing Technique</td>
<td>Sliding Mode Observer(SMO)</td>
</tr>
<tr>
<td>Technique(Bemf based)</td>
<td>InstaSPIN™-BLDC</td>
<td>InstaSPIN™-FOC TI FAST Algorithm</td>
</tr>
<tr>
<td>Voltage Sense</td>
<td>3x Vph</td>
<td>DC-Bus</td>
</tr>
<tr>
<td></td>
<td>3x Vph</td>
<td>3xVph + DC-Bus</td>
</tr>
<tr>
<td>Current Sense</td>
<td>Optional 1-shunt</td>
<td>1-3 shunt or phase</td>
</tr>
<tr>
<td></td>
<td>Optional 1-shunt</td>
<td>2-3 shunt or phase</td>
</tr>
<tr>
<td>Performance Speed</td>
<td>Poor dynamics</td>
<td>Poor low speed</td>
</tr>
<tr>
<td></td>
<td>Robust with load</td>
<td>Medium dynamics</td>
</tr>
<tr>
<td></td>
<td>Better Dynamics</td>
<td>Hard to tune</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Best low to high speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Best dynamics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Self Tuning</td>
</tr>
<tr>
<td>Performance Torque</td>
<td>High Torque, but Torque Ripple; slower dynamics</td>
<td>Ideal torque control, low noise, smooth operation,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>best dynamics</td>
</tr>
<tr>
<td>Motor</td>
<td>Trapezoidal wound</td>
<td>Sinusoidal wound</td>
</tr>
<tr>
<td>System Cost</td>
<td>Same</td>
<td>Sense additions</td>
</tr>
</tbody>
</table>
High-Speed Sensorless-FOC for drone ESC/
Challenges of FOC control
High-Speed Sensorless-FOC for drone ESC/
Challenges of FOC control

**SW**
- PWM features
- ADC sampling
- Electrical speed of motor
- Tuning of PI controllers
- Startup from zero speed

**HW**
- Voltage and Current sensing
- FET ratings
- Efficiency (Conduction and switching)
- Protection (OC, Short, OT)

**Angle**
- Mechanical Sensor
- Estimation algorithm
  - Tuning of algorithm for entire speed range
  - Motor Parameters
High-Speed Sensorless-FOC for drone ESC/
Challenges of FOC control

PI adjustment for your system

Angle and speed estimation does not need any more tuning
High-speed sensorless FOC for drone ESC / Current Controller Step Response

**High speed motor**
1200Hz equals 833us

**Fast current loop**
Current loop running at 22.5kHz equals 44us

**Enables**
Step response change is equal to approx. 400us

Meaning you can do approx. two speed changes per stable step response of the electrical frequency of the motor
Customer defined speed performance
Enable customer to differentiate with their specific speed profiles and dynamics response

Step response shown
Showing the step response chosen for high speed signal
High-Speed Sensorless-FOC for drone ESC / Speed reversal

High dynamic performance during speed reversal with acceleration of 36,000 RPM/s
Motor Size: (Diameter x Height): 21 x 15.5 mm
High-Speed Sensorless-FOC for drone ESC / TI Design TIDA-00916

**Features**

- High performance system solution for drone ESC using InstaSPIN™-FOC
- Sensorless high speed FOC control using TI’s FAST™ software observer
- High dynamic speed performance 1krpm to 10krpm (100Hz to 1kHz) in <0.2 s
- Tested motor speed of 1.2kHz Electrically (12000rpm with 11.2V battery with a 6 pole pair motor)
- Leveraging InstaSPIN-Motion C2000 LaunchPad and DRV8305 BoosterPack
- Easy example firmware for C2000 LaunchPad using MotorWare
- Supports 2 cell to 6 cell LiPo as typically used in drones
- Phase currents rating of 15A (Peak 20A)

**Benefits**

- Avoids interference with ultrasonic sensor due to capability to run PWM above 45kHz
- High efficiency FOC allows longer flight time
- Faster time to market due to no tuning of sensorless algorithm required stable from zero to maximum speed
- No need to know and measure motor parameters enables cost reduction
- Fast speed reversal capability for roll movement
- Fast acceleration for high performance yaw and pitch movement

**Target Applications**

- Non-military Drones
- High speed low inductance, low voltage 3-phase brushless motors

**Tools & Resources**

- TIDA-00916 and Tools Folder
- Design Guide
- Design Files: Schematics, BOM, Gerbers, MotorWare™, and more
- Device Datasheets:
  - DRV8305, TMS320F28069M, LMR16006, CSD18540Q5B

![Diagram of electronic speed controller](image-url)
Battery Pack for drone
Non – Military Drones – Subsystems

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**Remote**

**Battery Pack**
- 1s/2s/3Li-ion or Li-Po batteries, Supplies the Power to remote controller
• External battery voltage (blue curve) $V = V_{OCV} - I \cdot R_{BAT}$
• Higher C-rate $\rightarrow$ EDV is reached earlier (higher $I \cdot R_{BAT}$)

C-rate:
Current to discharge a fully charged Battery to EDV in one hour

SOC = State Of Charge

CEDV = Compensated End Of Discharge
Basic remainder

• Safety
  – Over Voltage
  – Over Current
  – Over Temperature

• User experience
  – Under Voltage
  – Cell Imbalance
What are the problematic for Drones Battery Pack

- Small form factor
- Low cost
- Difficulty to have an accurate gauge due to high discharge rate (3 to 5C)
  - CEDV good from 1C to 25-50C
  - Possibility to use Impedance Track
- 2S-4S platform
- Easy to evaluate
What is in the TIDA-00984

• Battery Charger
• CEDV Battery Fuel Gauging (P2P with Impedance Track)
• Battery Protection
• Battery Pack Cell Balancing
• Onboard State of Charge (SOC)
• SMBUS Communications for Advanced Status Updates
# Key Spec Charger

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATION</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charger efficiency</td>
<td>24V, 812-mA input -13.971 V, 1301-mA output</td>
<td>93</td>
<td>%</td>
</tr>
<tr>
<td>Charge voltage</td>
<td>Measured charge voltage</td>
<td>16.73</td>
<td>V</td>
</tr>
<tr>
<td>Charge current max</td>
<td>Measured charge voltage at max</td>
<td>1.311</td>
<td>A</td>
</tr>
<tr>
<td>Charger input minimum</td>
<td>Minimum voltage the charger would turn on</td>
<td>18</td>
<td>VDC</td>
</tr>
<tr>
<td>Charger input maximum</td>
<td>Maximum voltage the charger preformed to spec</td>
<td>28</td>
<td>VDC</td>
</tr>
<tr>
<td>Thermal test charger unit</td>
<td>(ambient 23.8°C) 1.3-A charge cycle</td>
<td>43</td>
<td>°C</td>
</tr>
<tr>
<td>Pre-charge complete</td>
<td>Comes out of pre-charge</td>
<td>3</td>
<td>V</td>
</tr>
<tr>
<td>Pre-charge minimum voltage</td>
<td>Minimum pre-charge voltage</td>
<td>2</td>
<td>V</td>
</tr>
</tbody>
</table>
# Key Spec Protection

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATION</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCD1 limit</td>
<td>Overcurrent limit during discharge</td>
<td>15000</td>
<td>mA</td>
</tr>
<tr>
<td>OCD1 delay</td>
<td>Overcurrent delay during discharge</td>
<td>20</td>
<td>S</td>
</tr>
<tr>
<td>OCD2 limit</td>
<td>Overcurrent limit during discharge</td>
<td>2,0000</td>
<td>mA</td>
</tr>
<tr>
<td>OCD2 delay</td>
<td>Overcurrent limit during discharge</td>
<td>10</td>
<td>S</td>
</tr>
<tr>
<td>AOLD limit</td>
<td>Analog front-end current overload limit</td>
<td>24</td>
<td>A</td>
</tr>
<tr>
<td>AOLD delay</td>
<td>Analog front-end current overload delay</td>
<td>15</td>
<td>mS</td>
</tr>
<tr>
<td>ASCD1 limit</td>
<td>Analog front-end short current limit 1</td>
<td>33</td>
<td>A</td>
</tr>
<tr>
<td>ASCD1 delay</td>
<td>Analog front-end short current delay 1</td>
<td>1,028</td>
<td>μs</td>
</tr>
<tr>
<td>ASCD2 limit</td>
<td>Analog front-end short current limit 2</td>
<td>44</td>
<td>A</td>
</tr>
<tr>
<td>ASCD2 delay</td>
<td>Analog front-end short current delay 2</td>
<td>244</td>
<td>μs</td>
</tr>
<tr>
<td>PARAMETER</td>
<td>SPECIFICATION</td>
<td>VALUE</td>
<td>UNIT</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Idle current for the gauge with regulator</td>
<td>Gauge active, MOSFETs on, gauge current for each cell, with a 3.3-V regulator</td>
<td>1.32</td>
<td>μA</td>
</tr>
<tr>
<td>Voltage regulator</td>
<td>Voltage of the 3.3-V regulator</td>
<td>3.31</td>
<td>VDC</td>
</tr>
<tr>
<td>Series impedance</td>
<td>Batt connector to pack connector series impedance, including MOSFET RDS's</td>
<td>0.0325</td>
<td>Ω</td>
</tr>
<tr>
<td>Thermal test under current for PCB</td>
<td>(ambient 23.8°C) 10-A constant current load</td>
<td>72</td>
<td>°C</td>
</tr>
</tbody>
</table>
TIDA-00984 Drone/Robot/RC 4S1P
Battery Management Solution

18-28Vdc
Power In
- Connector +

bq24600
Charger

Battery Management
Communications
3.3/5Vdc 300mA

SMBus Data
SMBus Clock

TPS62175
3.3/5V Reg

bq4050
Gauge/Protection/Balancing

Controller
Balancing

Gauge
Protection

Battery Pack
Li-Po
4S1P

Battery

Communications
+ Pack +

SMBus Clock
3.3/5V 300mA
TPS62175
3.3/5V Reg

TS Gauge
TS Charge
Board Picture

- Charger and Gauge external temperature sensor input
- Battery cells connector
- Batteries High current connector
- Pack High current connector
- 18 to 28VDC input
- SMBus Communications and external supply
Charge and Discharge cycle

Charge Cycle

Discharge Cycle
MOSFet temperature and SOC during a 10A Discharge
Thermal

1C Charge

10C Discharge
Non-Military Drone / Robot / RC 4S1P Battery Management Solution
Reference Design : TIDA-00984

Features
- Subsystem for a 4S1P Battery Management Solution for Non-Military Drone, Robot or RC projects and designs
- bq24600 Charger
- bq4050 Gauge, Protection and Balancing
- TPS62175 Adjustable Switching Regulator

Target Applications
- Non-Military Drone, Robot, RC (Radio Controlled) Car, Airplane, Helicopter
- Alternate applications using the bq40Z50: Portable audio, Medical, IoT and other portable devices that use a 4S battery solution

Benefits
- Compensated end of discharge voltage (CEDV) gas gauge accurately measures available charge in Li-Ion and Li-Polymer batteries
- Integrated cell balancing while charging
- Programmable protection features for voltage, current, temperature, charge time out, CHG/DSG FETs and AFE
- Diagnostic lifetime data monitor and black box recorder for your battery
- On board 3.3V/5V 300mA regulator to run an external controller

Tools & Resources
- TIDA-00984 and/or Tools Folder
- Design Guide
- Design Files: Schematics, BOM, Gerbers, Software, and more
- Device Datasheets:
  - bq4050 Product Folder
  - bq24600 Product Folder
  - TPS62175 Product Folder
How to extend flight time and battery life of quadcopters and industrial drones

Thank you for your attention!

References:

TI Designs showing 3 phase ESC:
TIDA-00916
TIDA-00643

For product selection on 3 phase ESC motor drivers:
TI 3 phase motor drivers

InstaSPIN-FOC:
Link

For more details on Motor Control:
Motor Control Compendium

References:

TI Designs for Drone Battery Pack:
TIDA-00982 – 2S
TIDA-00984 – 4S
TIDA-00553 - Multi-Cell Battery Manager Unit

Other TI Designs:
TIDA-00449 – 10s Battery Pack